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## AN APPROACH TO COMPLIANT MECHANISMS WITH PARTICULAR EFFECTS

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**Abstract:** *This paper presents a classification of the deformation behaviour of compliant mechanisms to simplify their systematic construction. The described mechanisms with fluid drive exemplify special effects of presented systematic. Compared to conventional miniaturizable bending structures the mechanisms discussed in this paper have advantageous properties such as larger movement range, greater flexibility and less sensory effort. Typical applications of the discussed mechanisms are medicine technology and robotics for gripping or manipulating tasks.*

**Key words:** *compliant mechanisms, fluid drive, classification*

### 1. INTRODUCTION

Due to the development of novel materials and corresponding manufacturing technologies, in many tasks concerning motion- or force-transmission conventional rigid body systems are more and more replaced or retrofitted successfully by coherent (consist only of one part) systems. The motion as well as the deformation of these structures, which are called compliant mechanisms, are realised by substance-to-substance hinges (substantial connected flexible assemblies) instead of the classical joints.

A compliant mechanism is defined in [1] as an exclusive or widely monolithically structure, which is movable in its structural elements on the basis of volitional elasticity. Generally the advantages of compliant mechanisms are: less friction and accordingly grease, good qualifications for miniaturisation, ease of manufacturing because of easier or no assembly and low maintenance. Furthermore, complex functional chains which are difficult to describe theoretically and fatigue of the material among large deformation have to be considered.

In the following a classification of compliant mechanisms regarding their compliance and their deformation behaviour is presented.

### 2. CLASSIFICATION OF COMPLIANT MECHANISMS CONCERNING THE COMPLIANCE

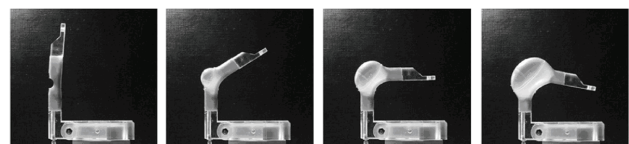
To ensure a meaningful construction using compliant mechanisms, it is necessary to specify a classification regarding their compliance. According to the drive configuration these mechanisms are grouped into compliant actuators whereat the energy conversion takes place at the compliant structural section and into gearing mechanisms which require an external force at the compliant sections to realize a movement. With respect to the compliance there are two kinds of them which can be registered – an fixed one and a variable one.

Structures having a fixed compliance which is explicitly defined by the construction's geometric and substantial parameters can adopt one or more equilibrium shapes for a given fixed load. Structures with one equilibrium shape have a one-to-one dependency of the deformation on the load. In case structures have several stable and instable equilibrium positions (static stability) for a fixed load only one particular equilibrium shape is defined by the user himself or by the environmental loads.

In case of structures having a reversibly variable compliance the latter can be changed by manipulating the geometry or by varying the structure's material properties. The compliance of these Structures can be divided into those with autonomously variable compliance and those with user-defined compliance. In the first changes of the compliance are caused by environmental conditions (loads, temperature, etc.) and in the second by the user himself.

#### 2.1. Stable Deformation-Behaviour of Compliant Structures - Monotonic Deformation

Figure 1 shows an example of the monotonic deformation behaviour of a pneumatically driven compliant structure. By increasing the load (here: internal pressure) the characteristic deformation parameters such as the angle between the longitudinal-axis of the rigid structural parts also increases [2].



*Fig.1. Monotonic deformation behaviour of a pneumatically driven compliant mechanism made of silicone rubber*

## 2.2. Stable Deformation-Behaviour of Compliant Structures – Behaviour with Direction Reversion

The deformation behaviour with direction reversion of a pneumatically driven compliant structure is shown in figure 2. The geometry of the structure is optimised, to achieve a reversion by loading the internal pressure. The horizontal displacement of the working element was chosen as one characteristic parameter, whereat the vertical displacement and the distance of the working element to the clamping are also possible characteristic parameters which can be taken into account. In the present case the increasing load initially yields to an extension of the horizontal displacement of the working element and finally causes a smaller displacement ([3]).

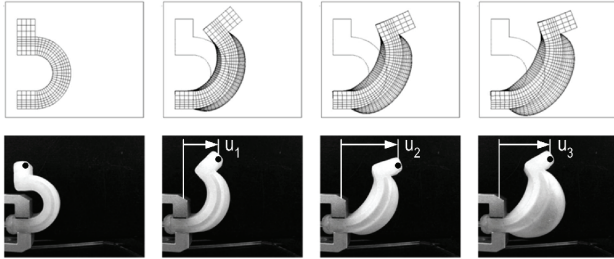


Fig.2. Static deformation behaviour with direction reversion of a compliant structure: at the top – FEM-calculations; at the bottom – compliant structure made of silicone rubber with characteristic parameters  $u_i$ ,  $i=1,...,3$  ( $u_2 > u_3 > u_1$ )

## 2.3. Instable Deformation-Behaviour of Compliant Structures - Snap-Through

In contrast to the stable deformation behaviour of compliant structures the instable case has more than one equilibrium position for a particular load. The instable deformation behaviour shows snap-through or bifurcation. In case of snap-through a sudden transition from one equilibrium position to another happens ([4], [5]). Thereby a given load corresponds to several equilibrium positions. In figure 3 a rotationally structure is shown having a half-toric curve around the spherical curve in the origin state. One characteristic feature of such a structure is the potential bistable deformation behaviour which can be enforced by the specified geometric parameters (shape, wall thickness, etc.).

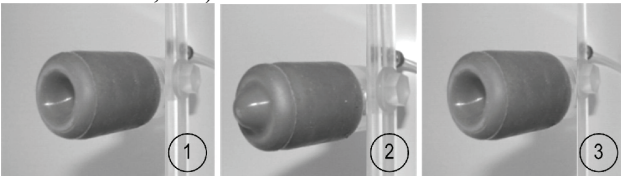


Fig3. Snap-through of a curved structure having a monostable deformation behaviour

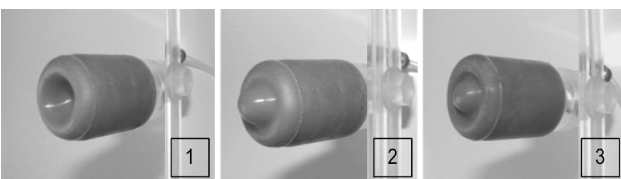


Fig.4. Snap-through of a curved structure having a bistable deformation behaviour

Two different structures with a big and small wall thickness are presented in figure 3 and 4, respectively. By increasing the load, the angular point (centre point) of the median curvature of both structures moves outwards until the critical load (Figure 5). Herein the value of the critical load is different to the named structures. An arbitrary small rise of load causes a huge displacement, as soon as the critical load is reached. In the process the median curvature penetrates completely (state 2 in figure 3-4). Removing the load causes the first structure to reverse to the original position (monostable deformation). This is demonstrated by state 3 in figure 3. The second structure switches to another equilibrium position (bistable deformation), named in figure 4 with state 3. A sketch of both characteristics and the calculated positions by means of FEM is shown in figure 5.

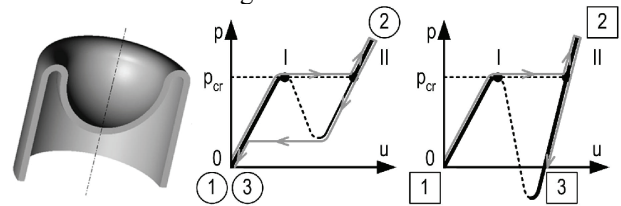


Fig.5. Sketch of Snap-through behaviour of a curved structure: structure with monostable deformation, structure with bistable deformation (r.)

## 2.4. Instable Deformation-Behaviour of Compliant Structures - Bifurcation

Situations in which load leads to bifurcation of structures are avoided systematically in engineering. The following theoretical analyses reveal some opportunities to apply this behaviour profitably to a technical system.

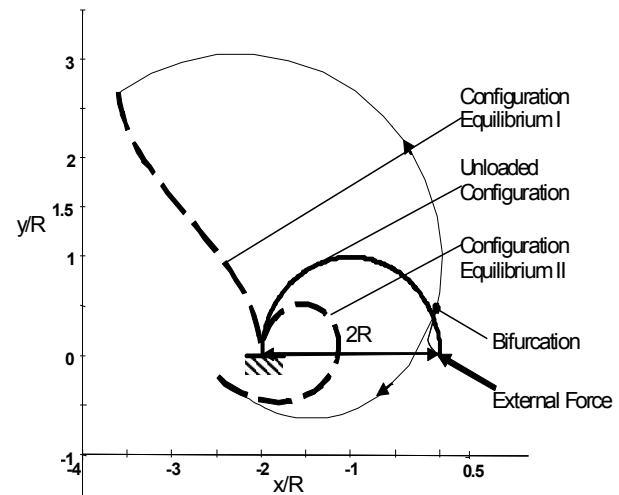


Fig.6. Equilibrium situations of a half-cycle shaped beam under external load; A force constant in amount and directions traces the free end of the beam

Best known examples for the loss of stability under static loads are the Eulerian cases of stability. For undercritical loads, the equilibrium is determinate, while at critical loads bifurcations in the solutions to state equations occur. Solutions are no more bijective, one load situation may lead to more than one possible geometric configuration of the system. Figure 6 exemplifies this phenomenon in the case of a half-cycle shaped bending

beam subject to loading by a single force with constant direction (conservative force) but with a 2D-free floating location of the site of application under load. Two possible trajectories of this point and two realisations of the equilibrium are illustrated. Solutions have been determined numerically, a current application is the design of compliant grasping devices.

### 3. CONCLUSION

The introduced classification which considers the deformation of compliant mechanisms is supposed to forward their development and to facilitate their implementation in rigid body systems or the functional expanded substitution of individual parts of the rigid body. The meaningful application of compliant mechanisms especially of such structures with instable static behaviour offers a great development potential. The role of the sensor system can be partly or completely adopted by “intelligent” mechanics. With the application of compliant structures and structural elements, which show an instable static behaviour and therefore segue from one state to another depending on external conditions, elementary characteristics of the system can change. Hence such systems will autonomously and directly adapt to the working conditions.

In relation with functional dominating compliant characteristics many application-oriented tasks like special valves, gripping-fingers with particular characteristics, medical structural elements and systems are conceivable.

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